Fiberoptic-based Synchrotron Radiation Diagnostics

…coupling the synchrotron radiation emitted by the beam into an optical fiber

PROS

- Synchrotron light can be taken to an easily accessible location, at a distance from the diagnostics port, inexpensively.
- Negligible attenuation and dispersion(0.5dB/Km, 0.1ps/nm^2 Km)
- Reliable components of common use in the telecommunication industry
- No electronic component has to be near the light port or in other inaccessible areas.

CONS

- Losses due to coupling of synchrotron radiation into the optical fiber (~ 3 dB ?)
- Might need compensation of transverse beam motion
- ~10% bandwidth is easily achievable. Larger bandwidths require special care (acromatic lenses, dispersion compensation, etc.)

Main Characteristics of the Optical Fiber

commercially available 1310 nm single-mode, non dispersion shifted fiber

This fiber, of standard use in telecommunications, seems to be the optimal solution, due to its excellent characteristics. It is available in a radiation hard variety as well.

Attenuation

~ 0.4 dB/Km

Dispersion

- nominal zero dispersion at 1310 nm
- total delay for 10% BW ≈ ***2 ps/100 m***

$$\Delta\tau = \Delta\lambda \, D(\lambda) \, L$$

$$D_\lambda = \frac{S_0}{4}\left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right)$$

Where:
S_0 = 0.092 ps/(nm^2 • km)
λ_0 = 1311 nm (Corning specifies a range of 1302-1322 nm. This number is the average.)
D_λ = Dispersion (ps/nm/km)

Uses of synchrotron Radiation for Longitudinal Diagnostics of the Beam

Streak camera - *Measurement of the beam longitudinal profile, bunch phase with picosecond resolution. (current ALS experiment)*

Optical sampling scope - *Mapping of charge density around the machine.*

Photodiode - *Accurate measurement of bunch charge (integrating over many turns, may need cooling).*

Gated Photomultiplier - *Used as abort gap monitor at the Tevatron. (PAC '05)*

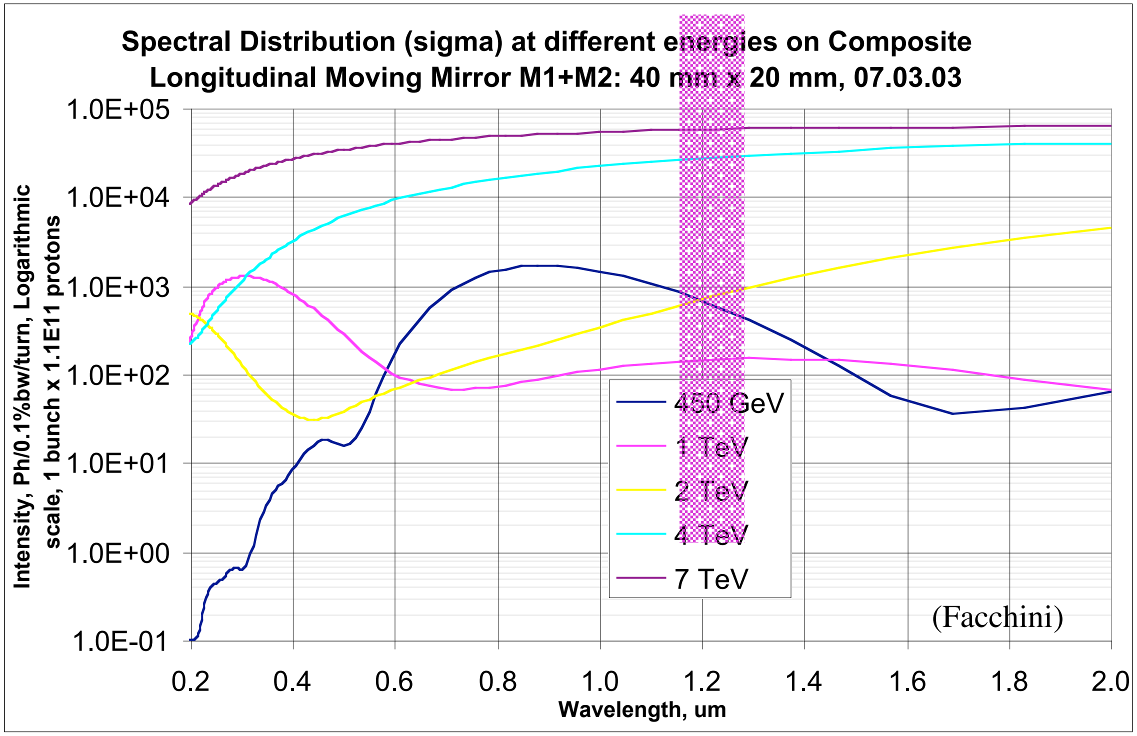
By using the synchrotron light transported on an optical fiber, it is possible to use many different devices on the same port. Instruments can be easily swapped and maintained, according to the particular situation.

Available photon fluxes from the LHC longitudinal diagnostics light port

The shaded area shows a 10% bandwidth around the 1310 nm wavelength.

At injection energy, the intensity is only five times lower than its maximum at 850 nm.

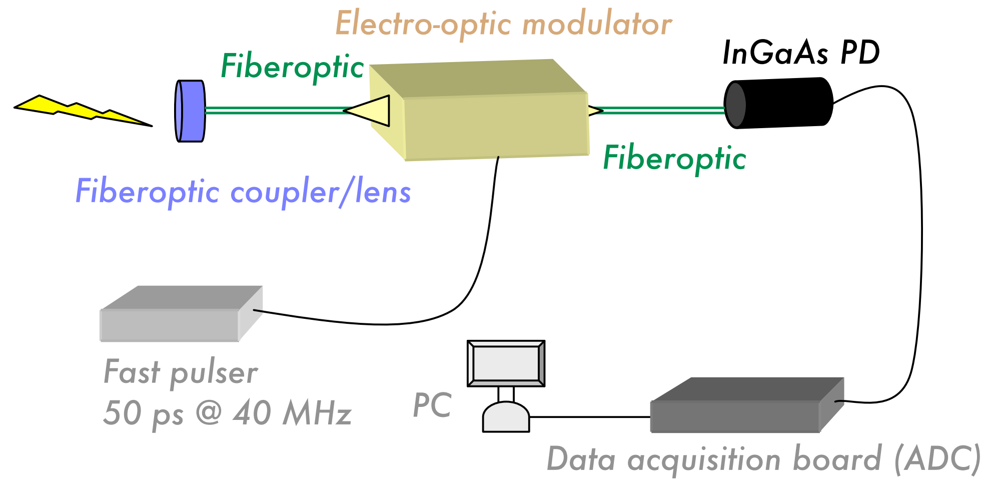
There is a factor of ~100 reduction in intensity between 7 TeV and 450 GeV.



Example: ghost bunches measurement at 7 TeV

LHC Requirements

- **Time resolution:**
  50 ps
- **Max integration time:**
  10 s
- **Sensitivity:**
  $5\ 10^5$ p



$5\ 10^5$ protons emit ~30 photons/turn in a 10% bandwidth.
The electro-optic modulator/fast pulser combination can map the entire LHC ring, with the required resolution, every 500 orbits.
In the allowed integration time, every single 50 ps-long region is sampled 200 times.
A 70% QE photodiode would accumulate >4000 counts.
We can estimate a total of -6/8 dB from the coupling into the optical fiber and the various insertion losses.
Main noise sources are the modulator extintion ratio (~ $3\ 10^{-3}$) and the photodiode dark current (~ nA)